

Memory cards: Designing with a full deck

WINNING AT POKER AND WINNING AT ENGINEERING HAVE AT LEAST ONE THING IN COMMON: A GOOD SET OF CARDS. PLAY YOUR HAND RIGHT—DISCARDING THE CARDS YOU CAN'T USE AND HOLDING ONTO THE ONES YOU CAN—AND YOU'LL END UP A WINNER. CHOOSE WRONG, THOUGH, AND THE CHIPS WON'T BE HEADED YOUR WAY.



ANY GOOD GAMBLER knows that, based on what's already in his or her hand, some card choices are better than others. Engineering is a gamble, too; in pushing the state of the art, you're often choosing from technology alternatives with unproven track records and, therefore, incompletely understood strengths and

shortcomings. Selecting a small-form-factor, removable-mass-storage module requires understanding not only the "black-box" characteristics, but also the cost and capabilities of the technology inside (**Table 1**).

Those characteristics also extend beyond the module to the system with which you interface it. For example, a memory technology's price might look attractive until you factor in the additional hardware and software you'll need to add to the host platform to communicate properly with it. Paying extra

money for a product with blazing speed makes no sense if bottlenecks elsewhere in the system negate any perceived performance boost. And an expensive, ultra-low-power storage technology is an unnecessary budget buster if other subsystems, such as the microprocessor or display, dominate total system power consumption.

ONE PLAYER FOLDS; ANOTHER TO FOLLOW?

In 1997, four leading form factors competed for your attention (**Reference 1**). Still popular PCMCIA (now also

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Illustration by Daniel Guidera

called PC) Cards—in 3.3-mm-thick Type I, 5-mm-thick Type II, and 10-mm-thick Type III formats—today have densities greater than 1 Gbyte. Both flash-memory and magnetic-media variants exist; flash-memory variants also come in nonremovable versions that are form-factor- and interface-compatible with hard-disk drives. Flash memory's cost per megabyte may be greater than that of rotating magnetic storage at larger densities; however, its greater immunity to shock, vibration, high temperatures, and other characteristics of harsh operating environments make it an attractive option if the information stored on the drive is more important to you than the drive's cost.

PCMCIA cards are, however, too big and too thick for many portable systems, opening the door for three similar-sized competitors. The Miniature Card, first championed by Intel and Sharp and later by AMD and Fujitsu, was born of a desire to decrease the card's footprint while preserving PCMCIA's parallel interface for high-bandwidth transfers. However, today's Miniature Card is for all intents and purposes a dead technology. (Intel, for example, recently sold its memory-card business to Centennial Technologies.) The lessons learned from the failure of Miniature Card provide a useful case study for both card-format-standards developers and system engineers selecting cards for their next designs.

In striving to squeeze PCMCIA's wide address, data, and control buses into the Miniature Card form factor, its founders employed a then-novel elastomeric connector that looked high-tech but was unreliable; it tolerated only a limited number of card insertions and removals. Cards and systems being shipped with replacement pads weren't particularly user-friendly and didn't instill much confi-

AT A GLANCE

- ▶ Balance each module's per-megabyte and fixed costs against the storage density your application requires.

- ▶ Required system hardware and software may negate a module's low media price.

- ▶ System bottlenecks may hinder a high-speed module, and intelligent-controller design can make a slow media seem fast.

- ▶ Digital-media-security requirements have opened another round in the proprietary-versus-industry-standard tug of war.

- ▶ Consider all the types of systems that your chosen card needs to interface with, and make sure there's credible connectivity in each case.

- ▶ Users might want to plug cards other than your preferred standard into your system; make appropriate hardware and software accommodations.

dence in the connector approach. Miniature Card's only significant design wins were a digital voice recorder from Olympus, a short-lived series of Windows CE-based personal digital assistants from Philips, and digital cameras from HP and Konica, which shifted to CompactFlash for subsequent camera generations.

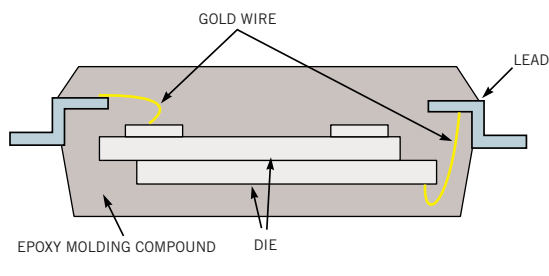
None of these systems took advantage of the fast random reads that were the inherent strengths of both the Miniature Card interface and the NOR (sometimes called linear) flash memories inside the cards. In fact, the EPROM-derived NOR flash chips' slow program and erase performance, coupled with their large erase-block sizes, left the approach at a disadvantage in the write-mostly applications

that define most of the market opportunity. To keep costs down, Miniature Card contained no onboard memory controller, although it contained rudimentary logic for system-to-flash-memory-bus translation, and none of the Miniature Card backers developed a system-based memory controller.

Lack of a memory controller forced system designers to rely on file-management software running on the host CPU. However, this approach burned more power and was slower than the hardware-assisted alternative. Porting this flash-file system to multiple microprocessors and operating systems also proved challenging. A few suppliers still offer linear flash cards in PCMCIA and Miniature Card formats, and Centennial Technologies recently unveiled a proprietary Compact Linear Flash format. However, most of the industry's now focuses its attention elsewhere.

Look at SmartMedia cards, formerly known as solid-state floppy-disk cards (SSFDCs), and you'll see some disturbing similarities to, along with some important differences from, Miniature Card. SmartMedia is just another packaging option for the NAND flash-memory die inside. In fact, all the card manufacturers interviewed for this article resell SmartMedia modules originally made by Samsung and Toshiba instead of designing their own. Like Miniature Card, SmartMedia modules contain no memory controller. Unlike Miniature Card, though, the system interface has a low pin count, which indicates that, unless you're directly executing code out of the card, wide parallel address and data buses are unnecessary, especially when a series of card reads and writes address consecutive flash-memory-array locations. The SmartMedia contacts hark back to those on smart cards.

Figure 1



Dual-die packaging and multipackage stacking (a) and multiple-layer pc boards (b) are three means of squeezing the most density into small form factors (courtesy Hitachi Semiconductor and Simple Technology, respectively).

S3/Diamond Multimedia's Rio PMP-300 and PMP500 audio players and Fuji Film and Olympus' digital still cameras constitute a disproportionately large percentage of SmartMedia's sales. Although the cards are popular in the Asia Pacific region, they haven't achieved widespread application or worldwide adoption. Initially, SmartMedia cards contained only a single flash-memory die, which limited their density. Smaller lithographies and redesigns of the chips' internal select logic relieved this limitation. Latest generation devices contain two die, and, conceptually, Toshiba's paper-thin package supports even more. As densities increase, however, troubling incompatibilities caused by system-design limitations have cropped up. Olympus had to recall some of its cameras so that they could work with high-density SmartMedia modules,

and Rio PMP300s don't recognize 64-Mbyte SmartMedia cards.

You also can't necessarily interchange a card between, say, an audio player and a digital still camera without reinitializing the card each time—obliterating the data that the card contains in the process. The SmartMedia specification standardizes only the electrical and mechanical interfaces and the low-level flash-memory command set—not the higher level system-file format. SmartMedia has other shortcomings, too. The contacts are exposed, leading to ESD concerns. Also, the package is very thin and has a broad surface, so it feels flimsy and easy to break. To handle the media-management duties, you can employ a system-based hardware controller. (Both Samsung and Toshiba supply reference designs.) Or, as with Miniature Card, you can run a file

system from Datalight, e.Digital, M-Systems, Phoenix Technologies, or Tokyo Electron Devices or one of your own design. Nearly all SmartMedia-based designs go the hardware route.

Indicative of SmartMedia's limited density expansion and other issues, the latest high-resolution Olympus cameras include both SmartMedia and CompactFlash slots, and the upcoming next-generation Rio audio player will also shift away from SmartMedia. In both cases, consumer perception, not application reality, drives the transition. A 64-Mbyte capacity, after all, is more than enough to store an hour of 128-kbit MP3 music and twice that if you choose 64-kbit Windows Media Audio. And, although digital cameras are dramatically improving their resolution-per-dollar value proposition, lossy image compres-

CONNECTIONS ARE CRITICAL

What if some of the systems you want to interface your small-form-factor, removable-mass-storage device to don't have a compatible connector and software? A number of Universal Serial Bus (USB) and parallel-port-based peripherals and even a few external SCSI peripherals exist. These options primarily target Windows and Macintosh platforms, but, in some cases, you can adapt them to other operating systems (Figure A).

Lexar Media has incorporated a USB core into its CompactFlash memory controller. The core lets you directly treat the device as a USB peripheral instead of running the card through an adapter (Figure B). Sandisk is all worked up about this situation, citing possible added cost and claiming that Lexar Media's deviation from the CompactFlash specification will confuse consumers. Sandisk's arguments may be unfounded if Lexar Media's claims of full backward compatibility with conventional CompactFlash are true. Added costs are Lexar Media's—not Sandisk's—issue to worry about, and



Figure A Multiple card formats and multiple system interfaces are no problem for an adapter (courtesy Delkin Devices).

this concern is counterbalanced by the fact that consumers don't have to buy a separate USB adapter. Sandisk may just be worried that customers will get hooked on Lexar Media's proprietary value-added approach.



Figure C The 3.5-in. floppy-disk drive might be ubiquitous, but don't expect it to deliver fast reads and writes (courtesy SmartDisk).

ISA-based memory-card reader/writers also exist, usually with native support for PCMCIA. To translate between PCMCIA and other card formats, you need another adapter. In the case of all small-card formats other than CompactFlash, this adapter includes bus-translation logic and perhaps even voltage-conversion circuits.



Figure B Integrate a Universal Serial Bus core alongside the CompactFlash interface and add a cheap cable, and high-speed file transfers are your reward (courtesy Lexar Media).

If none of these suggestions work and you've got a floppy disk drive in your system, then look to SmartDisk's FlashPath adapters, which currently support Memory Stick, MultiMedia cards, and SmartMedia cards (Figure C). Keep in mind that, in all these cases, the read/write performance bottleneck may end up being in the system interface, not the card itself. SmartDisk even makes a cassette adapter that reads MP3 files off a memory card and transforms them into magnetic information that your audio tape deck can then play.

sion using algorithms such as JPEG moderates the incremental per-picture file sizes. Professional photographers employ much less aggressive compression to retain high image quality, some-

times even switching to a lossless file format, such as TIFF. Along with video-clip storage for handheld computers and multihour digital-audio jukeboxes, professional-class digital cameras are the

primary users of the multihundred-megabyte cards now on the market.

CompactFlash has achieved by far the most widespread popularity of today's small-form-factor card formats, and for

WHERE'S THE BOTTLENECK?

I supplemented my last data-and file-storage article with a hands-on project Web-site addendum. The project evaluated flash-memory performance (write, read, and delete) in numerous card form factors, with multiple file sizes, and across a variety of systems with different performance levels and card interfaces (**Reference A**).

My observations, briefly summarized, were:

- Linear flash-memory cards' strengths were in read-intensive applications, but they trailed the rest of the pack in write-intensive usage.
- When it came to write performance, the biggest suppliers didn't necessarily have the best technology.
- In many cases, bottlenecks elsewhere in the system limited inherent memory-performance differences (if the cards were otherwise fast), and access caching hid these differences (if the cards were slow).

Given that the results not only matched my before-the-fact gut feeling, but also contradicted many of the vendors' marketing pitches, I wondered whether any of them would ever again let me evaluate their chips and cards.

It's three years later, and I'm revisiting the topic of small-form-

factor, removable mass storage. And again, I'm going to do some performance benchmarking. With the exception of Intel, all the vendors from the 1997 study are back, plus I'm including some new entries. This analysis is taking place in a business environment in which Lexar Media is claiming high performance as its primary differentiator and sells the same-sized card at different prices based on differences in write speed. It's also an environment in which Lexar Media and Sandisk are at odds with each other over patent violations (if those patents are even valid), CompactFlash enhancements, and whether "click-to-view" and "click-to-click" delay measurements should begin with the press or release of the shutter button.

The systems I'll be using for this year's study include:

- A Windows 98, 600-MHz, Pentium III-based desktop PC with parallel port and USB connections;
- A Windows 98, 166-MHz, Pentium multimedia-extensions-based notebook PC (HP 800CT) with PCMCIA slots and parallel-port connection;
- A Windows 95, 75-MHz, i486DX4-based notebook PC (HP 600C) with PCMCIA slots and a

- parallel-port connection;
- A Windows CE 2.0, 75-MHz Hitachi SH3-based HPC (upgraded Compaq C140) with PCMCIA slots;
- Older Kodak (DC-120) and newer Nikon (Coolpix 990) digital cameras with CompactFlash slots.

The contenders are (**Figure A**):

- AMD's 8-Mbyte (based on UltraNAND flash) CompactFlash card,
- Hitachi's 8-Mbyte (based on standard AND flash) and 96-Mbyte (based on multilevel-cell AND flash) CompactFlash cards,
- IBM's 340-Mbyte (based on a 1.3-in. MicroDrive) CompactFlash card,
- Iomega's 40-Mbyte Click! disk and PCMCIA-, parallel-port- and Universal Serial Bus (USB)-based drives,
- Kingston Technology's 128-Mbyte (based on AND flash) CompactFlash card and 520-Mbyte (based on Calluna Technology's 1.8-in. hard-disk drive) PCMCIA Type III card,
- Lexar Media's 64-Mbyte 8× and 160-Mbyte 10× (both based on NAND flash) USB-enhanced CompactFlash cards,
- Micron's 10-Mbyte (based on NOR flash) CompactFlash card,
- M-Systems' 32-Mbyte (based on NAND flash) CompactFlash card,
- Samsung's 32-Mbyte (based on NAND flash) SmartMedia card,
- Sandisk's 32-Mbyte (based on double-density NOR flash) CompactFlash card,
- Silicon Storage Technology's 8-Mbyte (based on

NAND flash) CompactFlash card,

- SiliconTech's 128-Mbyte (based on AND flash) CompactFlash card,
- Sony's 32-Mbyte (based on NAND flash) Memory Stick and PCMCIA adapter, and
- Toshiba's 64-Mbyte (based on NAND flash) SmartMedia card.

Adapters enable me to convert CompactFlash and SmartMedia cards to PCMCIA interfaces. I'll also re-evaluate the cards that I benchmarked in 1997 to see how the technologies they're based on might have evolved over the past three years:

- Kingston Technologies' 2-Mbyte (based on 16-Mbit NAND flash) SmartMedia card,
- NexFlash Technologies' 12-Mbyte (based on 1-Mbyte EEPROM flash) PCMCIA Type I card,
- Sandisk's 15-Mbyte (based on standard NOR flash) CompactFlash card, and
- Smart Modular Technologies' 4-Mbyte (based on 16-Mbit NAND flash) CompactFlash card.

Check out the Web-site version of this article for a link to the addendum that includes all the details and results. And keep in mind that the study focuses less on measuring the best possible read and write speeds than on quantifying the performance that an average user would experience.

REFERENCE

A. Dipert, Brian, "The great flash memory shootout (round 1)," www.ednmag.com/reg/1997/070397/df01_fls.htm.



Figure A

Make way for the contenders; here comes the benchmarking (Smart Modular Technologies card not shown).

good reason. The card and interface specifications are openly licensed, and the standards organization enjoys broad industry participation. (However, companies still seem to find lots to disagree about in court, such as card mechanical-assembly- and memory-controller-design patents.) CompactFlash memory cards employ a standard ATA/IDE command protocol that simplifies system-software development.

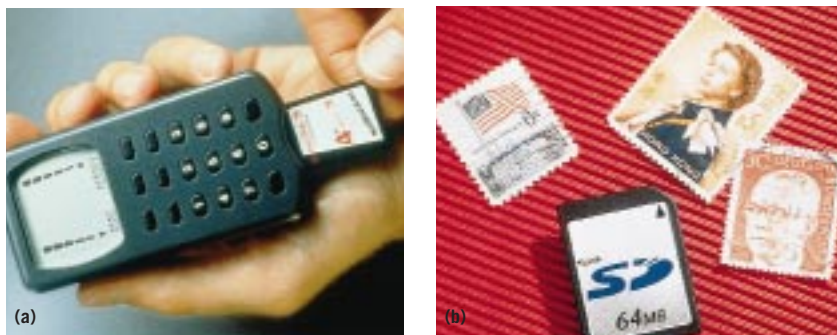
ATA compatibility, regardless of the media technology inside the card, and corresponding file-allocation-table (FAT) file-format standardization, increase card vendors' sourcing flexibility and enable card portability among systems (see sidebar "Connections are critical"). Two card thicknesses increase the range of available storage capacities and open the door to rotating magnetic-storage alternatives (Figure 1). And, in conjunction with a more flexible CF+ system interface, the wider thickness option even lets vendors (as with PCMCIA) put functions other than file storage in the card. Socket Communications has used this approach with its network adapters and other products, and Kingston Technology sells a CF+ 56-kbit analog modem, for example.

SECURITY OPENS ANOTHER ROUND

Believe it or not, a CompactFlash card is still too large for some systems. The size problem most significantly affects cellular phones, but it can also impact applications, such as ultrasmall digital-audio players (Figure 2). In response, Sandisk partnered with Siemens (now Infineon), which had developed a small ROM-based media-playback card. The two companies offered the MultiMedia card (MMC) to the electronics industry in an open-license fashion similar to the one used for CompactFlash, and the MMC has achieved predictably similar success. It comprehends both the industry-standard SPI and the faster MMC transfer protocols.

Unlike CompactFlash, the MMC currently supports only data and file storage, by virtue of its small size and seven-pin serial interface, although the MMC Association is currently considering specifications for I/O-card options. However, this narrower focus is less of a limitation than it might appear to be. Cellular phones already have built-in connectivity, for example, and many systems ap-

Figure 2



MultiMedia cards (a) target systems too small for today's memory modules. Secure Digital cards (b) are a secure (and more proprietary) version (courtesy Sandisk).

Figure 3



Memory Stick works interchangeably in digital cameras, computers, LCDs, audio devices (a), and even cyber canines (b), but the world might not yet be ready for a direct brain interface (c) (courtesy Sony).

propriate for MMCs can also integrate a Universal Serial Bus, Bluetooth, or other wired or wireless transfer protocols. Neither the MMC nor its CompactFlash predecessor currently incorporates robust

security, such as encryption/decryption logic, although both include an optional identifier unique to each card. In this era of digital-media proliferation and widespread copyright-violation concerns, this

limitation is a key concern that has opened the door to alternative card formats.

Sony has for some time now been promoting its Memory Stick, but only in recent months has the technology really hit its stride. The card's form factor, reminiscent of a piece of chewing gum, currently stores 64 Mbytes of data, with future capacity upgrades hinging on corresponding component-density growth. By early 2001, Sony plans to offer the Memory Stick Duo, with a separate $20 \times 31 \times 1.6$ -mm media block that you can detach from the cartridge block. Compared with cards that preceded it, Sony's offering has some compelling selling points. Because Sony controls the module specifications, the company can ensure a high level of intersystem compatibility. You can use the same card in a variety of applications, and each application sees only the information stored on the card that is appropriate for it (Figure 3). For example, a digital still camera reads and writes only image files and ignores sound or video clips that might also be present on the card. Recent expansion of the Memory Stick interface enables it to also work with imaging and networking devices, and file-format enhancements planned for this summer will enable application exchange of geographic-location information.

Memory Stick's secure media protocol, Magic Gate, requires a special version of Memory Stick. Predictably, security hardware and software details are available to licensees only under nondisclosure. To this point, you cannot ignore Sony's dominant consumer electronics presence and marketing muscle. However, the face-off between Memory Stick and other card formats so far seems to be shaping up as yet another reenactment of the Beta-versus-VHS wars that the company lost in the past. Sony has the right, of course, to extract license and royalty fees from other companies that implement its technology. Although Sony has assembled an impressive list of licensees, it's unclear how many of them will actually bring Memory Stick products to market, especially if those products compete with similar offerings from Sony.

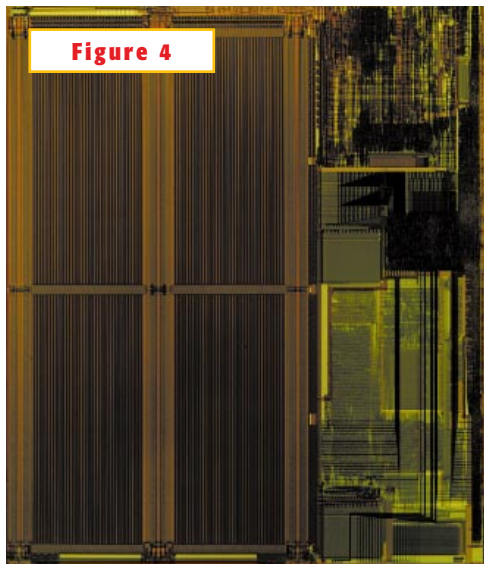


Figure 4
Combine the memory controller and storage array on the same die and maximize storage capacity with the tiny MultiMedia Card (courtesy Hitachi).

A printer manufacturer, for example, might include a Memory Stick slot (as well as connectors and software support for other card formats) in its next ink-jet design, but won't necessarily extend that Memory Stick support to its own digital cameras. General Motors (GM) has announced that it plans to incorporate Memory Stick support into future automobile subsystems, such as, you might speculate, audio equipment and back-seat LCDs. But in this endeavor, GM is acting as Sony's partner, not competitor, and nothing precludes GM from also supporting other popular card formats.

The MMC Association (MMCA) has been debating a secure-card variant for some time now, but a finalized specification has yet to materialize. Frustrated by the consortium's slow progress (a common shortcoming of any industry-stan-

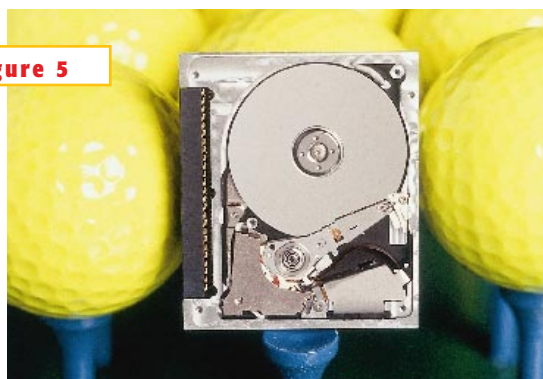


Figure 5
MicroDrive is a marvel of miniaturization in search of a market (courtesy IBM).

dards body) and alarmed by the secure Memory Stick plans of their formidable competitor, consumer-electronics giants Matsushita/Panasonic and Toshiba joined forces and, along with Sandisk, developed the Secure Digital (SD) card. SD cards are slightly thicker than MMCs (an MMC-compatible, narrower version is also under consideration), both to make room for the increased security logic and to allow for greater storage capacity. SD cards also grow the interface count to nine contacts (both for security reasons and to increase the I/O-bus width from one to four pins) but are otherwise identical to their MMC predecessors. In fact, an SD-aware system design can also use MMCs (in a nonsecure manner, of course).

SD marks an intriguing departure from past behavior for Sandisk. (Sandisk remains an active participant in the MMCA). Whereas Sandisk in the past championed two openly communicated card formats, CompactFlash and MMC, it and its partners are this time around following a restricted-access license and royalty model similar to the one Sony uses. The SD card has, at least initially, established some momentum and support with the Secure Digital Music Initiative (SDMI) consortium, and depending on when that specification becomes final, may achieve some design wins in digital-audio record-and-playback devices. However, broad system adoption beyond products made by Matsushita/Panasonic and Toshiba is yet to be determined. SD Association representatives claim that system manufacturers desiring to incorporate SD-card support don't have to pay royalties. They need pay only a yearly several-thousand-dollar SD Association membership fee, as well as licensing fees to the 4C Entity (www.4centity.com) and optional fees for access to SDMI watermarking technology. The upcoming digital-media-security article in *EDN's* June 22, 2000, issue will explain in greater detail the encryption aspects of SD cards.

The SD card's widespread success hinges on how quickly the MMCA finalizes its own secure-media standards. Just as Intel and Rambus' proprietary DRAM al-

liance lit a fire under JEDEC to wrap up the double-data-rate synchronous-DRAM specifications, SD has prodded the MMCA into action, led by Fujitsu, Hitachi, Infineon, and Sanyo. A variety of secure MMC proposals is on the table, including an SDlike expansion of the interface-pin count to nine or 13 contacts and a thicker card assembly. The Association intends to enable you to design a hardware socket that will interchangeably support secure MMCs, SD cards, and MMCs. However, secure MMCs will likely employ a security protocol incompatible with SD's Copy Protection for Recordable Media (CPRM) algorithm, which will somewhat complicate your software development. Stay tuned; preliminary versions of secure-MMC standards, as well as more details on secure-MMC licensing and royalty fees, may be publicly available by press time.

DISSECTING THE GAME

Don't get so caught up in the conflicting card specifications that you ignore the storage media inside them. The choices you make here have important cost, performance, power, and reliability implications. You'll be torn, too, between established technologies with proven track records and younger, less-well-known start-ups. On paper, the start-ups might appear to better meet your needs, but they inject greater risk into the design process.

NOR technology has achieved widespread adoption in EPROM-replacement direct-code-execution applications; PC BIOS and cellular phones are the most visible examples. However, its presence in

the more write-intensive data- and file-storage applications, particularly in designs that don't mix code and data within a single chip, is much less dominant. As previously mentioned, when discussing Miniature Card, the largest NOR suppliers have achieved virtually no success in pure data- and file-storage systems; AMD and Fujitsu admitted NOR's limitations when they unveiled their UltraNAND technology. Multilevel-cell (MLC) techniques, such as Intel's StrataFlash, might lower cost per bit, but they exacerbate NOR's already-inferior program performance and increase erase-block sizes.

Some NOR supporters, however, continue to advocate the technology in write-mostly applications. Sandisk's products have been NOR-based since the company's inception. Sandisk is today's memory-card-market-share leader and has succeeded in bringing to production cards based on its 256-Mbit double-density MLC chip. However, Sandisk's recent alliance with Toshiba—blending its MLC techniques with Toshiba's NAND technology—calls into question its long-term commitment to NOR. (Toshiba's MLC efforts never made it beyond ISSCC papers.) Micron is shipping limited quantities of CompactFlash cards based on its MediaFlash component and matched memory controller, with higher densities coming later this year. STMicroelectronics has NOR plans of its own: a 64-Mbit MLC chip and controller. The company hopes to begin offering CompactFlash cards for sampling in October and plans to offer Memory Stick modules and 4-bit-per-cell MLCs.

In tailoring NOR technology to mass-

storage applications, a vendor might accept larger die with more array-decoding periphery logic to reduce erase-block size, making the media appear more hard-disk-drive-sectorlike. Relaxed reliability specifications, in conjunction with error detection and correction (EDAC) elsewhere in the card or system, can improve program and erase performance. Transferring high-voltage pumps, logic-state machines, and other circuits from each flash memory to the common memory controller reduces media costs. And other memory-controller optimizations—such as intelligent wear-leveling (spreading writes across all available chips); background erase and media cleanup when the system isn't accessing the card; multibyte, multiblock, and multichip parallel erase and programming; and extensive on-controller RAM buffering—can enhance the NOR media's (or any other flash technology) apparent speed.

EEPROM-derived flash memory, although it may have a larger cell than NOR flash, doesn't suffer from some of NOR's erase- and write-performance shortcomings. Atmel's DataFlash and Nexcom Technology's Serial Flash both employ EEPROM-based flash arrays. Atmel doesn't currently sell its low-density chips in module form, but smaller lithographies may soon change the vendor's plans. Curiously, Silicon Storage Technology (SST), which uses an EEPROM-derived flash cell as the basis for its code storage and execution chips, currently uses other vendors' NAND devices in its CompactFlash cards. However, the company reports that it has data-storage-op-

TABLE 1—REPRESENTATIVE SMALL-FORM-FACTOR, REMOVABLE-MASS-STORAGE MODULES

	Clk!	CompactFlash	MediaStik	Medi-Tag	Memory Stick	Memory Stick Duo media block)	MultiMedia
Size (in.)	2×2	1.43×1.69	1.77×0.59	2×0.75	2×0.85	1.22×0.79	1.26×0.94
Thickness (in.)	0.125	0.13 (Type I), 0.2 (Type II)	0.13	0.125	0.11	0.06	0.06
No. of interfaces	Not applicable	50 pin (female)	Eight contact	20 contact	10 contact	10 contact	Seven contact
Built-in memory controller?	No	Yes	No	No	Yes	Yes	Yes
Built-in security?	No	No	No	No	Optional	Optional	No
Available adapters	PCMCIA	PCMCIA	PCMCIA	PCMCIA	PCMCIA, 3.5-in. floppy-disk drive	PCMCIA, 3.5-in. floppy-disk drive (both planned)	PCMCIA, 3.5-in. floppy-disk drive

timized chips in development for future card implementation.

NAND vendors won't necessarily be upset if the popularity of SmartMedia cards wanes, because NAND technology is today's media of choice in Memory Stick modules and many CompactFlash cards. Most of Samsung's and Toshiba's chips ship with some nonfunctional blocks, which the on-card or in-system memory controller maps around. AMD differentiates its UltraNAND technology by shipping only high-cycling silicon with fully functional blocks, eliminating the need for system-level EDAC and making more efficient use of the available storage density. High-reliability media eliminates the need to store block-level EDAC bits, and UltraNAND also offers an expanded-function, backward-compatible command set. AMD's development partner Fujitsu relaxed its testing (thereby potentially boosting yields) and sells a mix of fully and partially good die. AMD also sells its NAND-replacement chip in the currently unique fine-pitch-BGA package, as well as in the multi-sourced TSOP II.

Toshiba's 256-Mbit NAND chip is in production, the vendor reports, and Samsung is offering an equivalent for sampling. AMD and Fujitsu, now spending most of their energy satisfying NOR-flash demand, offer a 64-Mbit UltraNAND device in limited production. By year's end, Sandisk and Toshiba hope to begin sampling the first fruit of their technology partnership, a 0.16- μ m-based, 512-Mbit device. With optional MLC technology the device can store 1-Gbit of information. And, by late next



Figure 6

Click! media's cheap, but the drive isn't, and watch out for the heat (courtesy Iomega).

year, the two companies plan to again double the size of their largest device to a 2-Gbit MLC version based on 0.13- μ m technology.

To translate between a generic system-hardware-interface and software-command set, and silicon-specific versions, you need a memory controller. Feiya Technology Corp, Lexar Media, Memory Corp, and Tokyo Electron all sell PCMCIA- and CompactFlash-to-NAND translation and media-management chips, and other vendors, such as Hitachi and Micron, bundle controllers with their memories. Some companies use a hardwired state machine, but Lexar Media, Micron, Sandisk, and SST all incorporate an 8-bit microcontroller on the memory-controller ASIC, running firmware. Firmware is the primary means today by which Lexar Media differentiates its 4 \times , 8 \times , and 10 \times cards. The numbers allude to the cards' claimed maximum write performance.

Lexar Media's techniques are portable to other card interfaces, too; the company recently signed a licensing agreement

with Sony that enables Lexar Media to act as an alternative source of Memory Stick modules and gives Sony access to Lexar Media's controller technology. Lexar Media is primarily a card vendor, but it also sells its controllers to other companies on a limited basis, provided that those companies don't compete with Lexar in the digital photography market. Lexar admits that the low processing speeds of older digital cameras will mask the card's write-performance improvements (see sidebar "Where's the bottleneck?").

Hitachi and Mitsubishi's AND approach, which, like NAND, employs "mostly good memory," is today's other dominant flash technology in data and file storage (Reference 2). Although the companies in mid-1998 introduced their 256-Mbit MLC (128 million cells, with 2 bits per cell) AND chip, Hitachi didn't succeed in ramping it into production until late last year, and Mitsubishi just began shipping samples of products made in its own fabs. According to data-sheet specifications, AND doesn't suffer the same degree of write-performance degradation that plagues other flash technologies that incorporate MLC storage. However, AND chips aren't currently manufactured on processes as advanced as their NAND counterparts, negating any cost-per-bit advantage that AND would otherwise obtain from MLC. Hitachi also offers a single-die, 64-Mbit non-MLC chip, also in a dual-die, 128-Mbit version. And, although some of Hitachi's partners indicate that a dual-die 512-Mbit MLC chip is on the way, Hitachi has no official comment at this time.

The fact that Hitachi makes both flash memories and H8 microcontroller-based memory controllers was the fundamental reason that Kingston Technology selected AND technology for its flash cards. Kingston saw Hitachi as a more reputable controller manufacturer than the small third-party controller vendors or the vendors that competed with Kingston as card suppliers that NAND vendors advocated, as well as a company with a robust patent portfolio and extensive patent cross-licensing agreements in place. On the other hand, some companies report that access to AND silicon is difficult unless they also purchase Hitachi's memory controller. For the cost- and space-constrained MMC, Hitachi has developed a tailored 128-Mbit MLC

PCMCIA (PC Card)	Secure Digital	Secure MultiMedia	Small PC	SmartMedia (SSFDC)
3.37 \times 2.12	1.26 \times 0.94	1.26 \times 0.94	1.77 \times 1.69	1.77 \times 1.46
0.13 (Type I), 0.2 (Type II), 0.41 (Type III)	0.08	Not yet available	0.13 (Type I), 0.2 (Type II)	0.03
68 pin (female)	Nine contact	Not yet available	68 pin (female)	22 contact
Yes	Yes	Yes	No	No
No	Yes	Yes	No	Optional
Not applicable	PCMCIA, 3.5-in. floppy-disk drive (both planned)	PCMCIA, 3.5 in. floppy-disk drive (both planned)	PCMCIA	PCMCIA, 3.5-in. floppy-disk drive

chip that incorporates the memory controller alongside the storage array on the same die (Figure 4).

Kingston doesn't sell just flash memory-based removable storage. The company's line of 260-Mbyte, 520-Mbyte, and 1-Gbyte DataPak drives, which Kingston developed with Calluna Technology, offers high densities and low cost per megabyte in Type II and Type III PCMCIA form factors. Integral Peripherals, which supplied 1.8-in. hard drives, is no longer in business, but Calluna Technology strives onward. However, Kingston admits that its DataPak drive sales are drying up as the more rugged flash-memory-based card alternatives increase in capacity and decrease in price.

In the early 1990s, Hewlett-Packard introduced the Kittyhawk series of 1.3-

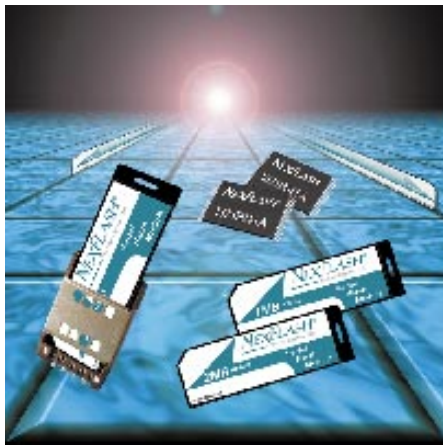


Figure 7 MediaStik is not the densest memory module, but it is one of the smallest and fastest (courtesy NexFlash Technologies).

in., 20- and 40-Mbyte hard-disk drives. Although the drives' cost per megabyte was more attractive than that of the flash memory of the day, they had a density-independent fixed cost that comprised the costs of the platters, the assembly, the interface electronics, and the other components. This "floor cost" makes a magnetic hard drive with a low density more expensive than a better-scaling semiconductor-based alternative. Plus, there was no such thing as a digital-audio market, and digital cameras were in their infancy. These factors all led to Kittyhawk's rapid demise. IBM revisits HP's vision with its 170- and 340-Mbyte MicroDrives, which IBM also sells in a Type II CompactFlash form factor (Figure 5). According to

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Centennial Technologies
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Dane-Elec
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Data-Disk Technology
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Delkin Devices
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e.Digital
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Feiya Technology Corp
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Hitachi Semiconductor of America
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IBM
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Infineon Technologies
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Interworks Computer Products
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www.iwcp.com
Enter No. 324

Iomega
1-801-332-1000
www.iomega.com
Enter No. 325

Kingmax Technology
1-949-454-9888
www.kingmax.com
Enter No. 326

Kingston Technology
1-714-435-2600
www.kingston.com
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Lexar Media
1-510-413-1200
www.lexarmedia.com
Enter No. 328

Matsushita Electric
1-201-348-7000
www.panasonic.com
Enter No. 329

Memorex
1-562-906-2800
www.memorex.com
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Memory Corp
1-408-524-8740
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Micron Technology
1-208-368-3900
www.micron.com
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Mitsubishi
1-408-730-5900
www.mitsubishichips.com
Enter No. 333

M-Systems
1-510-494-2090
www.m-sys.com
Enter No. 334

NexFlash Technologies
1-408-969-4700
www.nexflash.com
Enter No. 335

Phoenix Technologies
1-408-570-1000
www.phoenix.com
Enter No. 336

Pretec Electronics
1-510-440-0535
www.pretec.com
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the manufacturer, the 340-Mbyte version is the most popular.

If your application requires 100-Mbyte-or-greater densities, MicroDrives are one of the cheapest games in town. And, because they are based on giant-magnetoresistive-head technology, which also powers products such as IBM's recently introduced, 75-Gbyte desktop PC hard-disk drive, don't be surprised if you hear in the near future about even higher capacity MicroDrives. But even a brief look at the instruction manual quickly reminds you that you're dealing with a comparatively fragile rotating media. You're instructed to neither cover the ventilation hole on one side nor squeeze the sides together as you insert or remove the card.

Heat dissipation and power consumption negatively differentiate MicroDrive

from a silicon-based drive alternative, too. And dropping a MicroDrive-powered system while the drive's heads aren't parked is a probable path to data destruction. Digital-photography- and handheld-computer newsgroups sometimes contain postings from unhappy users who returned MicroDrives for more expensive flash-based storage alternatives. However, because people more often share their tragedies than their success stories, an accurate measure of MicroDrive's reliability remains elusive.

A FULL HOUSE

The small-format, removable-storage options discussed in this article are the most popular. Note that the term "small" excludes removable-storage alternatives that may be adequate for your use, such as Iomega Zip and Jaz disks, MiniDiscs,

CDs and DVDs, and SuperDisks (Reference 3). Ironically, SD-card-advocate Panasonic incorporates SuperDisks as an interim upgrade to the previously used 1.44-Mbyte, 3.5-in. floppy disk in some of its digital still cameras. Competitor Sony, which also used floppy disks in its early digital cameras, has transitioned to semiconductor-based Memory Stick for its higher resolution products. However, if nothing mentioned so far catches your eye, don't despair; the list of choices isn't yet complete.

Iomega's long-touted n-Hand storage module has been reborn as the Klik! Drive (Figure 6). The 40-Mbyte media's cost, less than \$10 (25 cents per megabyte) in multiunit bundles, is attractive. But that's just the disk cost. The rest of the drive, whether integrated in a PCMCIA, parallel port, or USB adapter

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Silicon Storage Technology

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Simple Technology and SiliconTech subsidiary

1-949-476-1130
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www.toshiba.com/taec
Enter No. 347

Viking Components

1-949-643-7255
www.vikingcomponents.com
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www.whiteedc.com
Enter No. 349

Wintec Industries

1-510-770-9239
www.wintecind.com
Enter No. 350

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CompactFlash Association

1-650-843-1220
www.compactflash.org
Enter No. 351

MultiMedia Card Association

1-408-253-0441
www.mmca.org
Enter No. 352

Personal Computer Memory Card Interface Association (PCMCIA)

1-408-433-2273
www.pcmcia.org
www.pc-card.com
Enter No. 353

Secure Digital Association

1-831-637-4545
www.sdcard.org
Enter No. 354

SSFDC Forum

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OTHER COMPANIES MENTIONED IN THIS ARTICLE

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www.agfa.com

Atmel

www.atmel.com

Fuji Photo Film

www.fujifilm.com

General Motors

www.gm.com

Hewlett-Packard

www.hp.com

Integrated Silicon Solution

www.issiusa.com

Intel

www.intel.com

Kodak

www.kodak.com

Konica

www.konica.com

Nikon

www.nikon.com

Olympus

www.olympus.com

Philips

www.philips.com

Rambus

www.rambus.com

S3 and Diamond Multimedia subsidiary

www.s3.com

Sanyo

www.sanyo.com

Sharp Microelectronics

www.sharpsma.com

Socket Communications

www.socketcom.com

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or built into your system, is much more expensive. Iomega is evasive on details, but the PCMCIA adapter costs \$149 from the vendor's Web site, even after a \$50 rebate. Allowing for retail-channel markups due to marketing and distribution costs and subtracting the cost of the single Klik! disk that Iomega bundles with the adapter, the drive cost still approaches \$50. Iomega's competitors are touting the same estimated cost.

A drive with that large a price is hard to swallow for a consumer-electronics device that costs a few hundred dollars, and the drive-to-media high-to-low cost ratio becomes attractive only if you are buying lots of disks, thereby amortizing the drive cost. Like IBM's MicroDrive, Klik! is subject to the power, heat, and reliability concerns that plague any rotating-media device. Agfa has introduced a digital camera with a built-in Klik! drive, but the company hedged its bets by also offering a model that uses CompactFlash. Iomega is now positioning Klik! as a mini-Zip disk for notebook computers with PCMCIA slots but no built-in Zip-disk support. Depending on your per-



Figure 8
The armed forces exit the analog age (courtesy Sandisk).

spective, that move may be an expansion or a redirection of Iomega's marketing messages.

If you're not enamored with magnetic-pickup heads, you could try a laser. Ioptics appears to have faded away into the sunset, but DataPlay replaces it, touting 2001 availability of ultra-small, write-once, rugged, high-density optical media (**Reference 4**). Details on the vendor's Web site are scarce, but DataPlay is tar-

getting an approximately 500-Mbyte capacity. DataPlay's founders come from former hard-disk-drive manufacturer PrairieTek. The roughly 1-in.² media comprehends security, called ContentKey, that unlocks prerecorded portions of the disk, but its write-once nature makes it less flexible than rewriteable alternatives.

Turning to silicon-based modules, Panasonic sells not only multisourced PCMCIA, CompactFlash, SmartMedia, and SD cards, but also includes the Small PC Card products. (Centennial Technologies sells this product as the Half Card.) The Small PC Card is roughly half the size of a standard PCMCIA card, but, unlike CompactFlash, it supports PCMCIA's full 68-pin interface. The CardBus upgrade of a few years back increased the PCMCIA interface's maximum bandwidth; more recent enhancements (under the CardBay moniker) add support for USB and IEEE 1394.

NexFlash Technologies continues to plug away with its MediaStik modules (**Figure 7**). (NexFlash Technologies was formerly Nexcom Technology. Integrat-

ed Silicon Solution briefly acquired the company and then spun it off.) The vendor targets applications that don't necessarily need high densities but value a low-power, ultrasmall form factor with very high write performance (**Reference 5**). Sandisk's Personal Information Card (PIC) may become the next-generation dog tag for the US military. Soldiers will carry cards that store their medical records and other information (**Figure 8**). Data-Disk Technology's Medi-Tag targets similar applications. Check out these claimed Data-Disk capabilities:

- Has no interference with or degradation upon exposure to magnetic fields or contact with other tags;
- Is noncorrosive, chemical-resistant, and waterproof;
- Has no degradation of operations in environments contaminated by radioactivity, biological agents, or chemicals;
- Withstands radiation levels greater than 200 rems;
- Handles storage temperatures of -65 to $+150^{\circ}\text{C}$;



- Withstands shock of repeated dropping from 8 ft, repeated 20g bounce shocks, and random vibration;
- Survives water immersion to 50m for hours without affecting operation;
- Resists blowing sand and dust;
- Withstands long exposure to high humidity, salt, fog, rain, snow, and ice;
- Resists contamination by fuels, hydraulic fluids, lubricating oils, solvents and cleaning fluids, insecticides, and other chemicals;
- Can ascend or descend 2000 ft/minute from -2000 to $+60,000$ ft in atmosphere.
- Meets MIL-STD 461D/462D EMI requirements;
- Survives maximum 10-kV static voltages; the optional polymer protective sheath protects to more than 25 kV. □

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